Flora and vegetation of the Eastern Goldfields Ranges: Part 2. Bremer Range

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Abstract

A study of the flora and plant communities of the Bremer Range greenstone belt in the spring of 1994 recorded 267 taxa. Only eight weed species were recorded but this number is likely to increase if further work is carried out in a better season. The flora list included one species gazetted as rare and new populations of five rare or poorly known taxa. Three species appear to be endemic to the Bremer Range greenstone belt, one of which was collected for the first time.

Six community types were defined from 64 sites spread across the range. The distribution of these community types appears to be primarily controlled by edaphic factors including soil water holding capacity. The floristic classification is in broad agreement with previous work but shows finer-scale patterning. None of the floristic communities or the endemic taxa are presently reserved. There has been significant impact on the vegetation of this range by mining and mineral exploration.

Introduction

The geology of ranges of the Goldfields region of Western Australia has been subject to extensive and ongoing study due to their highly prospective nature. These ranges are generally of two types, the Archaean (2500 - 3700 My old) mafic and ultramafic rocks (generally referred to as greenstone) which have undergone various degree of metamorphosis, and the banded ironstone ranges of the same age. Both major geologies are found on some ranges.

Despite the heavy exploitation of the goldfield ranges for minerals for over a hundred years, a detailed knowledge of the flora and vegetation of the region is still lacking. The aim of this series is to report on detailed floristic studies undertaken on individual ranges (Gibson *et al.* 1997). The present paper deals with the flora and vegetation of the Bremer Range greenstone belt.

Study Locality

The Bremer Range is located 170 km east of Hyden (Fig 1). The range system is 60 km long, stretching from north of Mt Day to Mt Glasse in the south. The range system is largely greenstone with small outcrops of banded ironstone, and it forms the major relief feature of the area (Gower & Bunting 1976; Hunter 1991). The topography is nonetheless subdued given the long period of erosion that this landscape has undergone. Except for the low greenstone ranges, the area consists almost entirely of gentle undulating uplands dissected by broad valleys with chains of salt lakes. These salt lake systems are the remnants of a drainage system active at an earlier time (possibly Cretaceous) of higher rainfall. Widespread laterization of the granites and greenstones is believed to have occurred during the Tertiary *i.e.* the last 65 My (Newbey 1988).

The area experiences cool winters and hot dry summers (Newbey 1988). Mean annual rainfall at Hyden (170 km west of the range) is 336 mm while at Norseman (110 km east of the range) it is 275 mm. Annual evapotranspiration is high (2150 mm at Norseman, 2230 mm at Hyden).

Beard (1976) first described the major structural formations in the area and grouped his structural units into vegetation systems. The greenstone areas of the Bremer Range, Round Top Hill, Mt Day and an unnamed hill to the north west of Mt Day form his Bremer Range vegetation system. He briefly described broom bush thickets of *Allocasuarina* on the rocky knolls, foot slopes of *Eucalyptus dundasii* and *E. longicornis*, with the lower slopes occupied by an *E. salmonophloia* association. Beard's work was followed by a regional survey of flora and fauna of the eastern goldfields (How *et al.* 1988). In the report covering the Lake Johnson - Hyden cell, Newbey & Hnatiuk (1988) described the vegetation of the Bremer Range under two main headings, banded ironstone hills and undulating greenstone plains. The banded ironstone hills were dominated by *Eucalyptus* aff *wandoo* (= *E. livida*) along with *Allocasuarina campestris, A. corniculata* and numerous shrubby taxa. They note that at one location on the Honman Ridge the soil was supplemented by calcareous and sub-saline material from a salt lake system. The undulating greenstone plain was described as being covered by *Eucalyptus flocktoniae* woodland with an understorey of species such as *Exocarpos aphyllus, Melaleuca pauperiflora, Acacia pachyphylla* and *A. merrallii.*

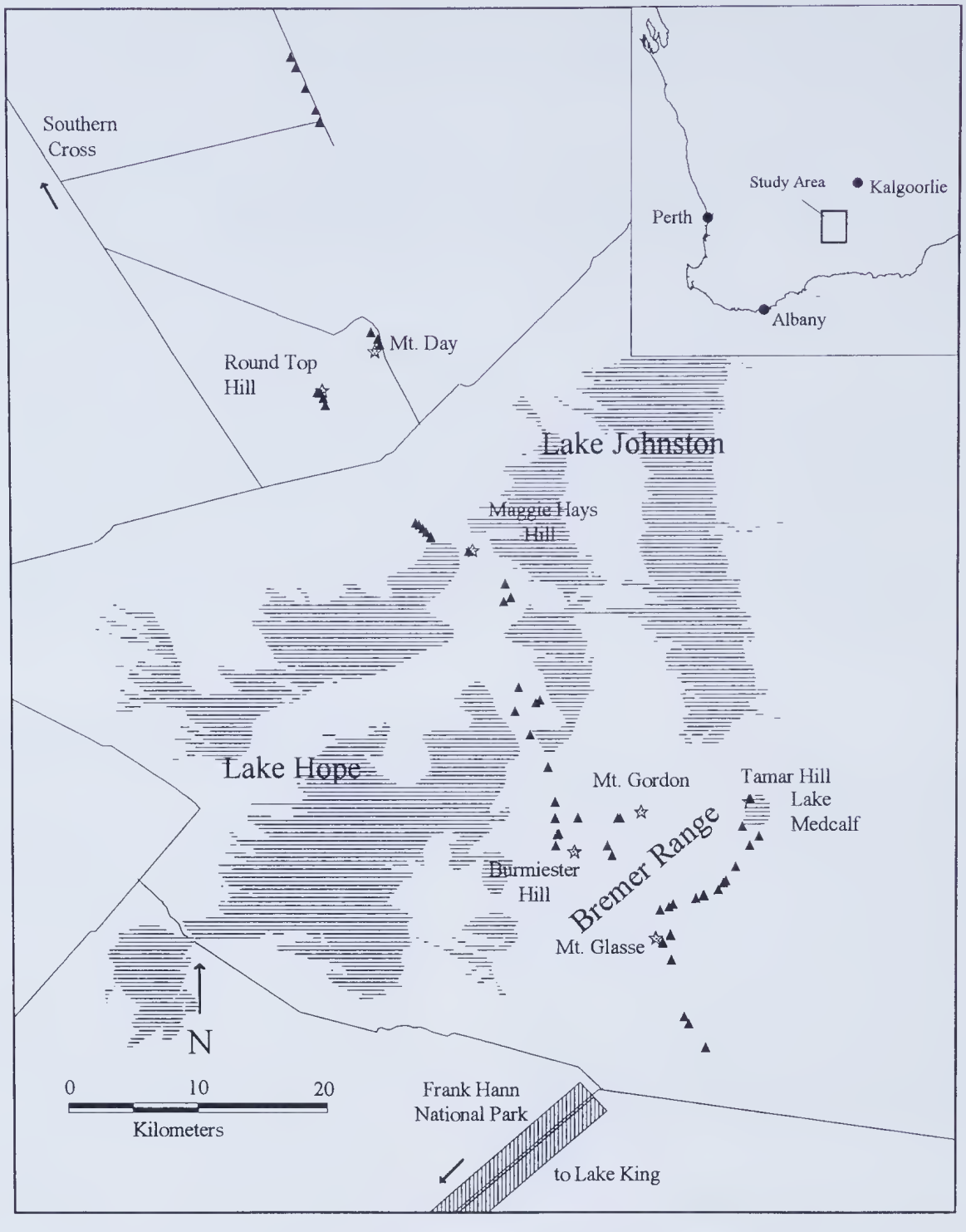

Figure 1. Location of study area. Individual sampling sites shown by solid triangles.

Both Beard's survey and the later biological survey of the eastern goldfields were undertaken to provide regional overviews. Consequently the individual greenstone ranges were not sampled extensively. Indeed, access to much of the Bremer Range was not possible at the time of these surveys. More recent work of the Bremer Range-Mt Day area has reported the occurrence of very diverse eucalypt woodlands (N Hall, CALM, and SD Hopper, Kings Park Botanic Garden, pers comm).

Methods

Sixty four 20 m x 20 m quadrats were established on the Bremer Range greenstone belt. The sites attempted to cover the major geographical, geomorphological and floristic variation. Care was taken to locate sites in the least disturbed vegetation available in the area being sampled. All sites were located in the undulating greenstone plain and banded ironstone hills units of Newbey (1988).

Within each site all vascular plants were recorded. The sites were only visited once during the spring of 1994. This was a poor year for annuals and it could be expected that the species richness of most sites would increase significantly if revisited during a good season. Data on topographical position, slope, aspect, vegetation structure and condition were collected from each site. Topographical position was scored on a subjective five point scale from ridge tops (1) to broad flats (4) to dunes beside salt lakes (5). Slope was scored on a one to three scale from flat (1) to steep (3). Aspect was recorded as one of 16 cardinal directions. Vegetation structure was recorded using Muir's (1977) classification.

All sites were permanently marked with four steel fence droppers and their positions determined using a GPS unit. Twenty four soil samples from the upper 10 cm were collected from each site. These were bulked and analysed for electrical conductivity, pH, total N, total P, percentage sand, percentage silt, percentage clay, exchangeable Na, exchangeable Ca, exchangeable Mg, and exchangeable K (Gibson *et al.* 1997).

Sites were classified according to similarities in species composition of perennial taxa. The spring of 1994 was dry with only patchy occurrence of annuals and geophytes. The classification undertaken used the Czekanowski coefficient and "unweighted pair-group mean average" fusion method (UPGMA; Sneath & Sokal 1973). Species were classified into groups according to their occurrence at the same sites by using the TWOSTEP similarity algorithm (Austin & Belbin 1982) followed by UPGMA fusion. Alternate classifications were tried using the ALOC algorithm (Belbin 1987). The resulting classifications were largely similar and only the former will be discussed in detail.

Semi-strong hybrid (SSH) ordination of the site data was undertaken to show spatial relationships between groups and to elucidate possible environmental correlates with the classification (Belbin 1991). Statistical relationships between site groups for such factors as species richness, soil parameters, slope, aspect, *etc* were tested using Kruskal-Wallis non-parametric analysis of variance and Mann Whitney U-test (Siegel 1956).

Species nomenclature follows Green (1985) and current usage at the Western Australian Herbarium. Selected voucher specimens will be lodged in the WA Herbarium.

Results

Flora

A total of 265 taxa (species, subspecies and varieties) and two hybrids were recorded from the 64 plots or the adjacent area. The most common families were Myrtaceae (63 taxa), Asteraceae (24 taxa), Mimosaceae (17 taxa), Poaceae (14 taxa), Chenopodiaceae (13 taxa), Myoporaceae (12 taxa), Proteaceae (11 taxa), Orchidaceae (10 taxa) and Rutaceae (9 taxa). Family composition was very similar to and typical of the flora of the South Western Interzone (Newbey & Hnatiuk 1988).

The most common genera were *Eucalyptus* (30 taxa), *Melaleuca* (21 taxa), *Acacia* (17 taxa), and *Eremophila* (11 taxa). Weed species were rarely encountered (8 species recorded). The 1994 spring was very poor for annual taxa except on rocky slopes where runoff collected in small depressions. The few weed records result in part from the poor season.

During the survey, two new populations of *Eucalyptus cerasiformis* were located. This species is currently listed as Declared Rare Flora (DRF; Anon 1996). New populations of a further five taxa being considered for listing as DRF were also encountered during the survey (Table 1; K Atkins, CALM, *pers comm*).

Table 1

The number of new populations found during the survey of species being considered for gazettal as Declared Rare Flora (K. Atkins, CALM pers. comm.)

Taxon	Number of new populations
Allocasuarina globosa	2
Acacia truculenta ms	3
Cryptandra polyclada	2
Eucalyptus cerasiformis	2
Eucalyptus georgei subsp *georgei*	2
Eucalyptus rhomboidea ms	11

This survey significantly extended the known range of *Eucalyptus rhomboidea* ms which was previously known only from near Mt Glasse. This species also occurs on Mt Gordon to the east and north to Round Top Hill. A new species of *Billardiera* was found on a greenstone ridge near Tamar Hill. This taxon is completely glabrous with large blue flowers and is believed to be most closely related to *B. mollis* a rare taxon found in the Ravensthorpe Ranges, 100 km to the south (E. Bennett, pers. comm.). *Eucalyptus cerasiformis, Eucalyptus rhomboidea* ms and *Billardiera* sp nov (NG&ML 1776) appear to be endemic to the Bremer Range-Mt Day greenstone belt.

The present survey recorded 72 additional taxa from the Bremer Range area (*cf* Newbey & Hnatiuk 1988), reflecting better access to the Range than was possible a decade ago. Some of these additions are also a result of improved taxonomic knowledge.

Vegetation

Some species had to be amalgamated into complexes for the floristic analysis due to difficulty of differentiating between closely related taxa without good flowering material (*e.g. Hibbertia rostellata* complex, *Melaleuca pauperiflora* complex).

One hundred and seventy perennial taxa were recorded from the 64 quadrats in the Bremer Range greenstone belt. Fifty eight taxa occurred at only one site. These singletons have little effect on the community classification and were excluded, so the final data set consisted of 112 taxa in 64 sites. Species richness ranged from 3 to 20 taxa per site, with individual taxa occurring in between 2 and 36 sites.

In this analysis, site groups are discussed at the six group level which best reflected the scale of vegetation patterning observed in the field (Fig 2). The primary division seen in the dendrogram separates the

Table 2.

Sorted two way table of the Bremer Range greenstone sites showing species occurrence by community type. Site appear as columns, species as rows.

	COMMUNITY TYPE					
	1	2	3	4	5	6
TAXA						
Species Group A						
Acacia acuminata			*		* **	
Dodonaea microzyga var *acrolobata*			* *		* *	
Allocasuarina acutivalvis					* *	
Dianella revoluta	*				**	
Dodonaea lobulata					**	
Ptilotus obovatus			*		*	
Species Group B						
Acacia duriuscula		*				**
Allocasuarina globosa						**
Eucalyptus georgei subsp *georgei*				*		*
Cheilanthes austrotenuifolia					* **	**
Eucalyptus oleosa					**	**
Eremophila decipiens		*		*		
Species Group C						
Acacia baxellii ms		*	*			
Eucalyptus cerasiformis		*			* *	
Triodia scariosa	*				*	
Eucalyptus transcontinentalis	*	* *			*	
Grevillea oncogyne	**	* *				
Species Group D						
Acacia merrallii		* *		*		
Eucalyptus cylindrocarpa		*		*		
Eucalyptus longicornis x *oleosa*		*	*			
Grevillea pectinata		* *				
Species Group E						
Acacia uncinella					** **	
Hakea scoparia					****	
Chamelaucium ciliatum					* *	
Hemigenia teretiuscula					* *	
Melaleuca cordata					**	
Baeckea crispiflora					**	
Calothamnus quadrifidus					*** *	*
Dampiera tenuicaulis					* *	
Cryptandra polyclada					* *	
Hibbertia rostellata					* **	
Pomaderris forrestiana		*			*	
Species Group F						
Allocasuarina campestris		* **			***** ** **	
Comesperma volubile		*	*	*	*** *****	
Lepidosperma sp (GJK 7000)	*	*			*** ** ** *	
Eucalyptus livida					* ***** *	
Phebalium tuberculosum	*	* * * *		* * *	** * ***	
Melaleuca uncinata	* **				*******	
Westringia cephalantha	****	*	* *	*	**** *	
Beyeria brevifolia		* * *	*		** **	
Hakea commutata		**			**	
Trymalium myrtillus		*			***	
Phebalium filifolium		*			* * *	
Allocasuarina helmsii					*	*
Thryptomene kochii					* *	
Dodonaea bursariifolia	*				***	
Rinzia sessilis					** *	
Species Group G						
Acacia camptoclada	**			**		
Acacia hystrix	* **			*		
Daviesia benthamii	***	*				
Eucalyptus eremophila	******				*	
Melaleuca acuminata	**	*				
Melaleuca lateriflora	**					
Melaleuca pentagona	**					

Table 2 (continued)

	COMMUNITY TYPE					
	1	2	3	4	5	6
Species Group H						
Acacia deficiens ms	*** *	* **				
Eucalyptus rhomboidea ms	*******	* *			* *	
Grevillea acuaria	****	* * *			*	
Wilsonia humilis	* * *	** * *				
Boronia inornata subsp *inornata*	*	* *				
Cassytha melantha	**					
Pultenaea arida	**	*** *				
Melaleuca eleuterostachya	** *				*	
Melaleuca phoidophylla ms	*	* *				
Species Group I						
Acacia erinacea	* **	* * * * **		*		*
Daviesia argillacea	* *	*** * * * ******			** *	
Eremophila clavata ms	******	* * ** *********	*	*	*	
Dodonaea stenozyga	* *	*** * ***** **** * * *	* *			
Eucalyptus flocktoniae	* *	********** ******	** ****			
Exocarpos aphyllus	** *	**** * ** **	** **** *	*	* *	*
Melaleuca pauperiflora	*******	****** **** ** * ****	******* ***	* *		
Eucalyptus salubris	*	* ** * *** * **	**			
Santalum acuminatum	***	*** *** ** *	* *****	*	* * ** *	
Microcybe multiflora var *multiflora*	* *	* * * **	*			
Acacia pachypoda	*	* * * *	*	**	*	
Eucalyptus salmonophloia		* * *	**	* **	*	
Eucalyptus yilgarnensis		* *		*	*	
Acacia poliochroa		*** * ***** *	* *			
Eucalyptus dundasii		** *	**	*		
Eucalyptus tenuis		******	* *		* *	
Grevillea huegelii		* * *		* **		
Scaevola spinescens		*** *	* *	**	*	
Halgania rigida		* ***	* * *			
Eremophila alternifolia			*	**		
Species Group J						
Cassytha racemosa		**				
Eremophila densifolia subsp *pubiflora*		* **				
Eremophila psilocalyx	* *	** ** *	*			
Eucalyptus annulata		** * **	*			
Eucalyptus pileata		** ***** *	*			
Westringia rigida	**	******** *				
Eucalyptus calycogona		* * * *				
Species Group K						
Acacia truculenta ms		* *	*			
Atriplex acutibractea subsp *karoniensis*			* **			
Enchylaena tomentosa		*	**	*		
Eremophila interstans		*	*			
Atriplex vesicaria			** **	* **		
Rhagodia drummondii			* * *	* **		*
Eremophila rugosa ms			** *			
Chenopodium curvispicatum			*******			*
Maireana radiata			****** * *			
Sclerolaena diacantha			**********			
Zygophyllum apiculatum		* **	** ** *****	*		
Cassia nemophila		*	* *	*		*
Cratystylis conocephala		*	* * *	* *		
Eremophila scoparia	*	** *	****	* *		
Eucalyptus longicornis		*	** *	** *		
Ptilotus holosericeus		**	* * *	***		
Alyxia buxifolia		* *** *	*		*** *	
Stenanthemum intricatum	*	*	* *			* *
Olearia muelleri	* *	**** ** * *	* *	******	* **	*
Austrostipa elegantissima	*	** * ***** * *	** * ***	***	* * **	
Eucalyptus melanoxylon		* *		*		
Melaleuca lanceolata		**		*		

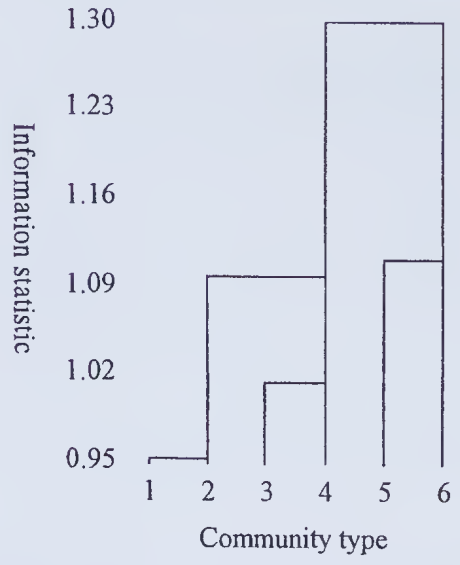

Figure 2. Dendrogram of the floristic sites from the Bremer Range area showing the six group level classification.

communities on deeper more fertile soil types (generally eucalypt woodlands, types 1 to 4) from the greenstone and lateritic ridge communities (woodlands and thickets, types 5 & 6). This division can also be clearly seen in the sorted two way table of the site and species classifications (Table 2).

- **Community type 1** generally occurs on the side slopes of low ridges and is typified by the high fidelity of species groups G and H (Table 2). This community type is typically dominated by *Eucalyptus rhomboidea* ms and *E. eremophila*. It was largely restricted to the Bremer Range proper but also flanked Round Top Hill (Fig 2). *Melaleuca* species in the *M. pauperiflora* complex were common components of the understorey in this community (and types 2 and 3). *Eremophila clavata* ms was also common in community types 1 (and type 2), while *Acacia deficiens* ms and *Grevillea acuaria* were largely restricted to community type 1.
- **Community type 2** was the typical *Eucalyptus flocktoniae* woodlands of the area. Other eucalypts co-occurring in this community included *E. salubris, E. salmonophloia, E. dundasii* and *E. tennis*. This community type largely lacked species of groups G and H, while species group I occurred at moderate to high frequency and species group J was largely restricted to it (Table 2). It may be possible to further divide this community into a northern and a southern subgroup based on species in groups I, J, and K. Typical understorey species included *Daviesia argillacea, Dodonaea stenozyga* and *Acacia poliochroa*. This community occurred on both broad flat ridges and side slopes.
- **Community type 3** was generally dominated by *Eucalyptus flocktoniae* and /or *Eucalyptus longicornis*. This community was typical of the more saline soils as indicated by the high fidelity of many species from species group K (*e.g. Chenopodium curvispicatum, Maireana radiata, Sclerolaena diacantha* and *Zygophyllum apiculatum*). Again, species in the *M. pauperiflora* complex were common in the understorey. This community was restricted to ridges and flats adjacent to the large salt lake systems.
- **Community type 4** is similar in species composition to type 3 but has a lower frequency of the saline-tolerant species (Table 2, species group K). It was often dominated by *Eucalyptus longicornis* and /or *E. salmonophloia* but can also be dominated by *E. georgei* subsp *georgei* or *E. dundasii*. This community generally had lowest species richness of any of the eucalypt woodlands (mean 8.9 taxa /plot *cf* 14.4, 12.0 and 11.8, for types 1 to 3 respectively) and tended to occur low in the landscape. *Olearia muelleri* was the most faithful of the understorey species.
- **Community type 5** was generally dominated by either *Eucalyptus livida* woodland (on the lateritic tops) or by *Allocasuarina* thickets (on the greenstone ridges). Species typical of this community include *Allocasuarina campestris* and *Lepidosperma* sp (GJK 7000); it was widespread throughout the Bremer Range area, mostly on lateritic breakaways. Species from species groups A, B, E and F were typical of both community type 5 and 6 communities (Table 2). Mean species richness in this community was 13.2 taxa /plot.
- **Community type 6** occurred on the massive greenstone ridges with skeletal soils. Typical species from species group B included *Acacia duriuscula, Allocasuarina globosa, Eucalyptus georgei* subsp *georgei* and *Eucalyptus oleosa*. Mean species richness was to 6.5 taxa /plot. Community type 6 was only found on a greenstone ridge south east of Maggie Hays Hill.

Environmental correlates

Correlation with soil and geomorphological parameters. The soil parameters in particular showed high levels of inter-correlation (Table 3). There was significant differences between floristic group means and some geomorphological parameters (Table 4), and most soil parameters measured (Table 5). Some care needs to be taken in interpreting these results as only two quadrats were assigned to community type 6 (Figure 2 & Table 2).

The highest fertility soils were those associated with community type 3, which generally occurred on large flats adjacent to salt lakes. The saline nature of the soils can be seen from the high electrical conductivity and high exchangeable cations, in particular Na. Soils from this community type had the highest pH, total N, total P, and highest exchangeable Ca, Mg, Na, and K. Soils from community type 2 were also fertile but had significantly lower pH, total P, and total N. This community type was found on broad flats and ridge tops but did not differ significantly from community type 3 in terms of altitude, topographic or slope class (Table 4).

Community type 4 also occurred low in the landscape but had soils markedly different from community type 3, with significantly lower electrical conductivity, pH, total N, exchangeable Mg and Na, but similar total P. Soil parameters were most similar to soils of community type 2 but with a significantly lower clay content. Community type 1 tended to occur on side slopes. Its soils had low total N and P and significantly lower exchangeable Ca and K than the other lower slope woodlands.

The soils of lateritic and greenstone ridge tops (community types 5 and 6) had low total N and P, low pH and very low electrical conductivity. These community types were restricted to skeletal soils, so total available

Table 3

Matrix of Spearman rank correlation coefficients between environmental parameters. Only correlations significant at $P < 0.01$ shown ($r > 0.3245$). See methods for soil parameter codes.

	Altitude	Aspect	Ca	Clay	Conduct	K	Mg	Na	Total N	pH	Total P	Sand	Silt	Slope	Topog
Altitude	1.000														
Aspect		1.000													
Ca			1.000												
Clay				1.000											
Conduct			0.662		1.000										
K			0.712		0.649	1.000									
Mg			0.692	0.475	0.736	0.617	1.000								
Na			0.491	0.434	0.829	0.524	0.799	1.000							
Total N			0.762		0.792	0.544	0.544	0.512	1.000						
PH			0.645		0.659	0.641	0.603	0.564	0.551	1.000					
Total P	-0.339								0.497		1.000				
Sand			-0.550	-0.822	-0.460	-0.552	-0.608	-0.499		-0.414		1.000			
Silt			0.691		0.504	0.664	0.475	0.334	0.556	0.540		-0.753	1.000		
Slope		0.635												1.000	
Topog															1.000

Table 4.

Bremer Range community type means for altitude, topographic position (1-ridge top to 4-valley flat), slope class (1-flat to 3-steep), aspect (16 cardinal directions) and species richness. Non significant differences between means indicated by same superscript ($P > 0.05$, Mann-Whitney U-test).

Community Type	Altitude (m)	Topography	Slope	Aspect	Species richness
1	377.1^{a}	3.1^{ab}	1.9^{a}	4.0^{ab}	14.4^{a}
2	360.0^{ab}	3.3^{ab}	1.8^{a}	2.8^{ab}	12.0^{ab}
3	351.7^{b}	3.2^{ab}	1.8^{a}	4.9^{b}	11.8^{ac}
4	374.3^{ab}	3.9^{a}	1.7^{a}	3.7^{ab}	8.9^{bc}
5	376.7^{a}	3.0^{b}	2.0^{a}	4.3^{ab}	13.2^{a}
6	360.0^{ab}	3.0^{ab}	2.0^{a}	7.3^{b}	6.5^{b}

Table 5

Bremer Range community type means for soil parameters. Non significant differences between means indicated by same superscript ($P > 0.05$, Mann-Whitney U-test).

Community Type	Electrical Conductivity ($mS\ m^{-1}$)	pH	N total (%)	P total (%)	% Sand	% Silt	% Clay	Exchangeable Ca (me %)	Exchangeable Mg (me %)	Exchangeable Na (me %)	Exchangeable K (me %)
1	19.4^{ab}	7.59^{a}	0.077^{a}	87.4^{a}	72.6^{ab}	12.5^{ab}	14.9^{ab}	7.7^{a}	4.14^{a}	0.94^{abc}	0.74^{a}
2	24.3^{a}	8.27^{b}	0.128^{b}	87.3^{a}	63.2^{a}	16.9^{b}	19.8^{a}	17.0^{b}	7.25^{bc}	1.11^{ab}	1.34^{bc}
3	41.3	8.43	0.204	143.3^{b}	67.4^{ab}	17.8^{b}	14.8^{ab}	20.1^{b}	7.58^{b}	1.61^{b}	1.63^{b}
4	20.0^{ac}	7.97^{ab}	0.119^{ab}	118.9^{ab}	71.7^{ab}	15.2^{ab}	13.1^{b}	13.8^{b}	4.76^{ac}	0.56^{ad}	1.43^{b}
5	7.2^{b}	6.43^{c}	0.097^{a}	101.0^{a}	73.7^{b}	12.0^{a}	14.4^{ab}	7.9^{a}	2.46^{d}	0.29^{e}	0.38^{d}
6	7.0^{bc}	7.15^{ac}	0.091^{ab}	80.5^{a}	68.8^{ab}	18.3^{ab}	13.0^{ab}	12.3^{ab}	3.70^{acd}	0.21^{cde}	0.57^{acd}

soil nutrients and soil moisture capacity would be very low. Because of the low number of samples of community type 6 it is not possible to characterise differences in soil parameters between the two upland community types.

Ordination results. Ordination of the sites was undertaken to show spatial relationships between groups and elucidate possible environmental correlates with the classification. The stress value was 0.23 for the three dimensional ordination. Superimposed on the ordination output (Figure 3) are best fit linear correlations of the environmental parameters measured using principal axis correlation (Belbin 1993). All parameters were range standardised prior to fitting.

The ordination shows a major gradient related to soil fertility, with community type 3 occupying the most fertile sites (Figure 3). At approximately 90 degrees to

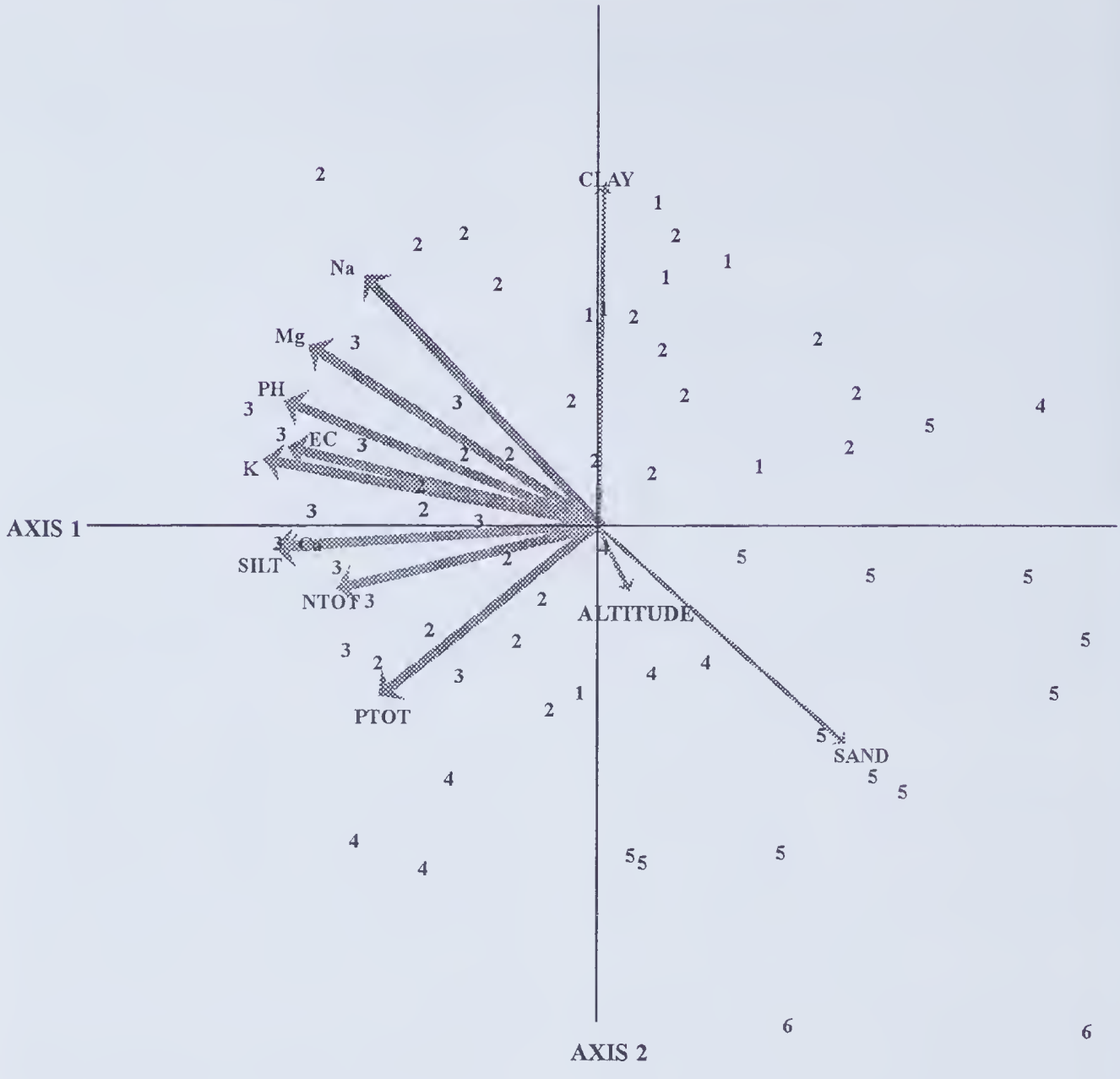

Figure 3. Ordination of Bremer Range floristic sites with numbers corresponding to community types. Arrows show the direction of the best fit linear correlation for environmental parameters. Narrow arrows are significant at $P < 0.05$, and broad arrows at $P < 0.01$, $n = 64$.

this gradient, a clear separation is seen between the ridge top communities (types 5 & 6) from the lower slope communities (Figure 3). The distribution of sites and the strong correlation with percentage sand in this direction suggests that a soil moisture availability gradient may be the secondary underlying gradient.

Discussion

Three endemic taxa have been recorded from the Bremer Range greenstone belt. This area lies within Hopper's (1979) Transitional Rainfall Zone which has undergone major fluctuations in annual rainfall during the Tertiary (last 65 My). Hopper (1979) suggested that these fluctuations have resulted in speciation centred on arid period refugia, and this may explain the number of local endemics reported from these areas. These endemics are not related to ultramafic substrates which are rare in the study area. Ultramafic areas are generally rich in endemic taxa due to the very unbalanced soil chemistry (Brooks 1987). The ultramafic areas sampled in this study showed no soil chemistry imbalance, possibly due to the very ancient nature of these formations and the subsequent long period of soil weathering.

The major differences between community types of the Bremer Range appears to be primarily related by

edaphic factors with an inferred moisture holding capacity as a secondary gradient. The ridge tops of laterites and greenstones generally had much lower soil nutrient status than the colluvial deposits down slope and the alluvial and colluvial deposits of the valley bottoms. The soils with the highest nutrient status (in terms of N and P) had the highest electrical conductivity and the highest exchangeable Na and Ca. They also occurred low in the landscape and their higher salinity probably reflects down slope leaching over most of the Tertiary.

The previous work undertaken in the study area described broad regional vegetation patterns (Beard 1976; Newbey & Hnatiuk 1988). Our results are generally consistent with those descriptions but show finer scale patterning. Some of the vegetation units described above (community types 1 - 4) are also described as occurring on the Broad Valley unit of Newbey & Hnatiuk (1988). Our study supports Beard's concepts of the Bremer Range Vegetation System (Beard 1976). One of our community types showed some north-south subdivision, another was very localised and the remaining four were spread throughout the greenstone belt.

None of Beard's (1976) Bremer Range vegetation system currently occurs in any conservation reserve; similarly the three endemic species on Bremer Range are completely unreserved. Significant conservation reserves have been proposed for the area around Mt Day and the Bremer Range proper (Anon 1992), however these are yet to be acted upon. The current proposals would adequately conserve both the flora and communities of the Range except for community type 6 which is only know from greenstone ridge south east of Maggie Hays Hill.

Both past and present mineral exploration activity are having a significant impact on the vegetation of this area, especially within small geomorphological units. We saw little evidence of rehabilitation of exploration tracks, costines or drill sites. There is an urgent need to improve environment management of mineral exploration on Vacant Crown Lands.

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References

Anon 1992 South Coast Region Regional Management Plan 1992-2002. Department of Conservation and Land Management, Perth. Management Plan 24.

Anon 1996 Wildlife Conservation (Rare Flora) Notice 1996. Government Gazette, Perth, WA, 5083-5087.

Austin MP & Belbin L 1982 A new approach to the species classification problems in floristic analysis. Australian Journal of Ecology 7:75-89.

Beard JS 1976 The vegetation of the Boorabbin and Lake Johnson areas, Western Australia. Vegmap, Perth.

Belbin L 1987 The use of non-hierarchical allocation methods for clustering large sets of data. Australian Computer Journal 19:32-41.

Belbin L 1991 Semi-strong hybrid scaling, a new ordination algorithm. Journal of Vegetation Science 2:491-496.

Belbin L 1993 Principal Axis Correlation In: PATN Users manual. CSIRO, Canberra

Brooks RR 1987 Serpentine and its Vegetation. A Multidisciplinary Approach. Croom Helm, Sydney.

Gibson N, Lyons MN & Lepschi BJ 1997. Flora and vegetation of the eastern goldfields ranges: Part I: Helena and Aurora Range. CALMScience 2: 231-246.

Gower CF & Bunting JA 1976 1: 250000 Geological series. Lake Johnson, Western Australia. AGPS, Canberra.

Green JW 1985 Census of Vascular Plants of Western Australia. Department of Agriculture, Perth.

Hopper SD 1979 Biogeographical aspects of speciation in the southwestern Australian flora. Annual Review of Ecological Systematics 10:399-422.

How RA, Newbey KR, Dell J, Muir BG & Hnatiuk RJ 1988 The Biological Survey of the Eastern Goldfields of Western Australia. Part 4 Lake Johnson - Hyden Study Area. Records of the Western Australian Museum Supplement 30.

Hunter WM 1991 1: 250000 Geological series. Borabbin, Western Australia. Geological Survey of Western Australia, Perth.

Muir BG 1977 Biological survey of the Western Australian wheatbelt. Part II. Records of the Western Australian Museum Supplement 3.

Newbey KR & Hnatiuk RJ 1988. Vegetation and Flora. In: The Biological Survey of the Eastern Goldfields of Western Australia. Part 4 Lake Johnson - Hyden Study Area (eds RA How, KR Newbey, J Dell, BG Muir & RJ Hnatiuk). Records of the Western Australian Museum Supplement 30:17-42.

Newbey KR 1988 Physical Environment. In: The Biological Survey of the Eastern Goldfields of Western Australia. Part 4 Lake Johnson - Hyden Study Area (eds RA How, KR Newbey, J Dell, BG Muir & RJ Hnatiuk). Records of the Western Australian Museum Supplement 30:7-16.

Siegel S 1956 Non Parametric Statistics for Behavioural Sciences. McGraw-Hill, New York,

Sneath PHA & Sokal RR 1973 Numerical Taxonomy: The Principals and Practice of Numerical Classification. Freeman, San Francisco.

Appendix 1

Flora list for the Bremer Range greenstone belt (* indicated introduced species). Taxa with collection numbers are lodged in the Western Australian Herbarium.

Adiantaceae
- *Cheilanthes austrotenuifolia*

Aizoaceae
- *Carpobrotus* sp

Amaranthaceae
- *Ptilotus holosericeus*
- *Ptilotus obovatus*

Anthericaceae
- *Borya constricta*
- *Thysanotus patersonii*

Apiaceae
- *Daucus glochidiatus*
- *Homalosciadium homalocarpum*
- *Hydrocotyle pilifera var glabrata*
- *Hydrocotyle rugulosa*
- *Platysace maxwellii*
- *Trachymene cyanopetala*
- *Trachymene ornata*

Apocynaceae
- *Alyxia buxifolia*

Asteraceae
- *Actinobole uliginosum*
- *Asteridea athrixioides*
- *Asteridea pulverulenta*
- *Blennospora drummondii*
- *Brachyscome iberidifolia*
- *Calotis hispidula*
- *Cratystylis conocephala*
- *Hyalosperma demissum*
- * *Hypochaeris glabra*
- *Isoetopsis graminifolia*
- *Millotia tenuifolia*
- *Olearia dampieri* subsp *eremicola* ms
- *Olearia muelleri*
- *Podolepis capillaris*
- *Podolepis lessonii*
- *Rhodanthe laevis*
- *Rhodanthe manglesii*
- *Rhodanthe oppositifolia* subsp *oppositifolia*
- *Rhodanthe pygmaea*
- *Senecio glossanthus*
- *Senecio* sp (NG & ML 2323)
- * *Sonchus oleraceus*
- * *Ursinia anthemoides*
- *Waitzia acuminata*

Boraginaceae
- *Halgania rigida*
- *Halgania viscosa*
- *Omphalolappula concava*

Brassicaceae
- *Stenopetalum robustum*

Caesalpiniaceae
- *Cassia nemophila*

Campanulaceae
- *Wahlenbergia gracilenta*

Caryophyllaceae
- *Stellaria filiformis*

Casuarinaceae
- *Allocasuarina acutivalvis*
- *Allocasuarina campestris*
- *Allocasuarina corniculata*
- *Allocasuarina globosa*
- *Allocasuarina helmsii*

Celastraceae
- *Psammomoya choretroides*

Chenopodiaceae
- *Atriplex acutibractea* subsp *karoniensis*
- *Atriplex vesicaria*
- *Chenopodium curvispicatum*
- *Enchylaena tomentosa*
- *Halosarcia entrichoma*
- *Maireana erioclada*
- *Maireana radiata*
- *Maireana trichoptera*
- *Rhagodia drummondii*
- *Sclerolaena diacantha*
- *Sclerolaena drummondii*
- *Sclerolaena eurotioides*
- *Threlkeldia diffusa*

Convolvulaceae
- *Wilsonia humilis*

Crassulaceae
- *Crassula colorata*

Cupressaceae
- *Callitris glaucophylla*

Cyperaceae
- *Gahnia lanigera*
- *Lepidosperma* sp (GJK 7000)
- *Lepidosperma* sp (KRN 7815)
- *Lepidosperma* sp (NG & ML 2075)
- *Schoenus nanus*

Dilleniaceae
- *Hibbertia rostellata* complex

Droseraceae
- *Drosera macrantha* subsp *macrantha*

Epacridaceae
- *Astroloma serratifolium*
- *Coleanthera myrtoides*
- *Leucopogon cuneifolius*
- *Styphelia pulchella*

Euphorbiaceae
- *Beyeria brevifolia*
- *Ricinocarpos stylosus*

Fabaceae
- *Daviesia argillacea*
- *Daviesia benthamii*
- *Gastrolobium crassifolium*
- *Mirbelia* sp (NG & ML 1881)
- *Pultenaea arida*

Geraniaceae
- *Erodium cygnorum*

Goodeniaceae
- *Dampiera tenuicaulis*
- *Goodenia dyeri*
- *Scaevola bursariifolia*
- *Scaevola spinescens*

Haloragaceae
- *Gonocarpus nodulosus*

Lamiaceae
- *Hemigenia teretiuscula*
- *Prostanthera grylloana*
- *Teucrium sessiliflorum*
- *Westringia cephalantha*
- *Westringia rigida*

Lauraceae
- *Cassytha glabella*
- *Cassytha melantha*
- *Cassytha racemosa*

Loganiaceae
- *Mitrasacme paradoxa*

Loranthaceae
- *Amyema miquelii*

Mimosaceae
- *Acacia acuminata*
- *Acacia andrewsii*
- *Acacia blaxellii* ms
- *Acacia camptoclada*
- *Acacia deficiens* ms
- *Acacia duriuscula*
- *Acacia erinacea*
- *Acacia hadrophylla* ms
- *Acacia hystrix*
- *Acacia lasiocalyx*
- *Acacia merrallii*
- *Acacia myrtifolia*
- *Acacia pachypoda*
- *Acacia poliochroa*
- *Acacia truculenta* ms
- *Acacia* sp (NG & ML 1959)
- *Acacia uncinella*

Myoporaceae
- *Diocirea microphylla* ms
- *Eremophila alternifolia*
- *Eremophila calorhabdos*
- *Eremophila clavata* ms
- *Eremophila decipiens*
- *Eremophila densifolia* subsp *pubiflora*
- *Eremophila deserti*
- *Eremophila dichroantha*
- *Eremophila interstans*
- *Eremophila psilocalyx*
- *Eremophila rugosa* ms
- *Eremophila scoparia*

Myrtaceae
- *Astartea ambigua*
- *Baeckea crispiflora*
- *Calothamnus quadrifidus*
- *Calytrix leschenaultii*
- *Chamelaucium* sp (NG & ML 1963)
- *Chamelaucium ciliatum*
- *Chamelaucium megalopetalum*
- *Eucalyptus annulata*
- *Eucalyptus calycogona*
- *Eucalyptus cerasiformis*
- *Eucalyptus cylindriflora*
- *Eucalyptus cylindrocarpa*
- *Eucalyptus densa* subsp *densa*
- *Eucalyptus dundasii*
- *Eucalyptus eremophila*
- *Eucalyptus flocktoniae*
- *Eucalyptus georgei* subsp *georgei*
- *Eucalyptus hypochlamydea* subsp *ecdysiastes* ms
- *Eucalyptus incerata* ms
- *Eucalyptus leptopoda*
- *Eucalyptus livida*
- *Eucalyptus longicornis*
- *Eucalyptus longicornis x oleosa*
- *Eucalyptus loxophleba*

Eucalyptus melanoxylon
Eucalyptus oleosa
Eucalyptus pileata
Eucalyptus platycorys
Eucalyptus rhomboidea ms
Eucalyptus salicola
Eucalyptus salmonophloia
Eucalyptus salubris
Eucalyptus sheathiana
Eucalyptus tenuis
Eucalyptus transcontinentalis
Eucalyptus yilgarnensis
Eucalyptus yilgarnensis x gracilis
Leptospermum fastigiatum
Melaleuca acuminata
Melaleuca cardiophylla
Melaleuca cliffortioides
Melaleuca cordata
Melaleuca coroniocarpa
Melaleuca eleuterostachya
Melaleuca fulgens
Melaleuca hamulosa
Melaleuca lanceolata
Melaleuca lateriflora
Melaleuca pauperiflora
Melaleuca pentagona
Melaleuca quadrifaria
Melaleuca sheathiana
Melaleuca phoidophylla ms
Melaleuca podicarpa ms
Melaleuca sp (NG & ML 2320)
Melaleuca sparsiflora
Melaleuca teuthidoides
Melaleuca torquata
Melaleuca uncinata
Micromyrtus obovata
Rinzia sessilis
Thryptomene australis
Thryptomene kochii

Orchidaceae
Caladenia microchila
Caladenia saccharata
Caladenia sigmoidea
Cyanicula caerulea
Genoplesium nigricans
Pterostylis mutica
Pterostylis sanguinea
Pterostylis sargentii
Thelymitra antennifera
Thelymitra aff *pauciflora*

Phormiaceae
Dianella revoluta

Pittosporaceae
Billardiera sp nov (NG & ML 1776)

Plantaginaceae
Plantago debilis
Plantago aff *hispidula* (NG & ML 1732)

Poaceae
* *Aira cupaniana*
Aristida contorta
Austrostipa elegantissima
Austrostipa platychaeta
Austrostipa scabra subsp *scabra*
Austrostipa trichophylla
Bromus arenarius
Danthonia caespitosa
Danthonia setacea var *setacea*
Neurachne alopecuroidea
* *Pentaschistis airoides*
Triodia scariosa
* *Vulpia bromoides*
* *Vulpia myuros*

Polygalaceae
Comesperma volubile

Portulacaceae
Calandrinia eremaea

Proteaceae
Grevillea acuaria
Grevillea huegelii
Grevillea oncogyne
Grevillea paradoxa
Grevillea pectinata
Grevillea teretifolia
Hakea commutata
Hakea cucullata
Hakea multilineata
Hakea scoparia
Persoonia helix

Rhamnaceae
Cryptandra minutifolia subsp *brevistyla*
Cryptandra polyclada
Pomaderris forrestiana
Stenanthemum intricatum
Stenanthemum pomaderroides
Trymalium myrtillus

Rubiaceae
Opercularia hispidula

Rutaceae
Boronia aff *fabianoides* (NG & ML 2313)
Boronia inornata subsp *inornata*
Boronia ternata var *ternata*
Eriostemon fitzgeraldii
Eriostemon pachyphyllus
Microcybe multiflora var *multiflora*
Phebalium filifolium
Phebalium megaphyllum ms
Phebalium tuberculosum

Santalaceae
Exocarpos aphyllus
Exocarpos sparteus
Santalum acuminatum

Sapindaceae
Dodonaea bursariifolia
Dodonaea caespitosa
Dodonaea lobulata
Dodonaea microzyga var *acrolobata*
Dodonaea stenozyga
Dodonaea viscosa subsp *angustissima*

Solanaceae
Anthocercis genistoides
Lycium australe
* *Solanum hystrix*

Sterculiaceae
Rulingia luteiflora

Stylidiaceae
Levenhookia pusilla

Urticaceae
Parietaria debilis

Zygophyllaceae
Zygophyllum apiculatum
Zygophyllum glaucum